

Numerical Investigation of the Effects of Buoyancy Production Terms in Predicting the Lateral Spread of a Propane Flame¹

M. Ashrafizaadeh, E. Weckman and A. B. Strong

Dept. of Mechanical Engineering

University of Waterloo

Waterloo, Ontario, Canada, N2L 3G1

An elliptic fire model [1] has been developed and used to numerically investigate the validity of the commonly used $k - \epsilon$ turbulence model and its modified variations in simulating buoyancy dominated diffusion flames. The present model consists of 2D time averaged conservation equations for mass, momentum and energy. Turbulence is modeled using the $k - \epsilon$ turbulence model and the Eddy Dissipation Concept is used for combustion. Flame radiation is also accounted for by a constant fraction assumption. The governing equations are solved using a pressure based control volume method on a collocated variable arrangement.

This model is used to simulate the 2D rectangular propane flame of Annarumma et al. [2]. Details of the numerical setup used in the present simulations (e.g. boundary conditions, grid size, etc.) can be found in [1]. Figure (1) shows the predicted velocity and temperature fields. Although centerline values of the vertical velocity and temperature are predicted reasonably well, the lateral spread of the fire is clearly underpredicted (as reported by other authors as well, e.g. [2, 3]).

The analysis of a detailed set of data obtained from medium scale methanol pool fires [4] shows that the buoyancy production term, $g\overline{v'\rho'}$, in the turbulent kinetic energy equation has a positive contribution in the vicinity of the fire base. However, the widely used gradient hypothesis gives a modeled form for the buoyancy production term which is proportional to $\partial\rho/\partial z$. The density gradient is negative in the region adjacent to the fire base where temperature is rising. This causes the buoyancy production term to become negative and suppress turbulence in that region. The latter may partially explain the underprediction of the fire spread.

To investigate the effects of the buoyancy production term in the k equation, the results obtained from a case where all values of $\partial\rho/\partial z$ are accounted for (*case I*) are compared with the results obtained from another case where only positive values of $\partial\rho/\partial z$ are considered (*case II*). Results show that turbulent

Reynolds numbers for *case II* are much higher than those for *case I*. In fact, the values of Re_t for *case I* near the fire base are so low that the validity of using any turbulent fire model is questionable.

The lateral profiles of vertical velocity and temperature at different heights above the burner are shown in Figures (2) and (3) and compared against experimental data. As evident in these figures, considering only positive values of buoyancy production in the k equation improves the lateral spread of the fire at the cost of lowering the centerline values. Therefore, it appears necessary to model the buoyancy production term such that a positive contribution is ensured. For improved overall accuracy of the numerical results a more accurate chemistry and radiation models will also be required.

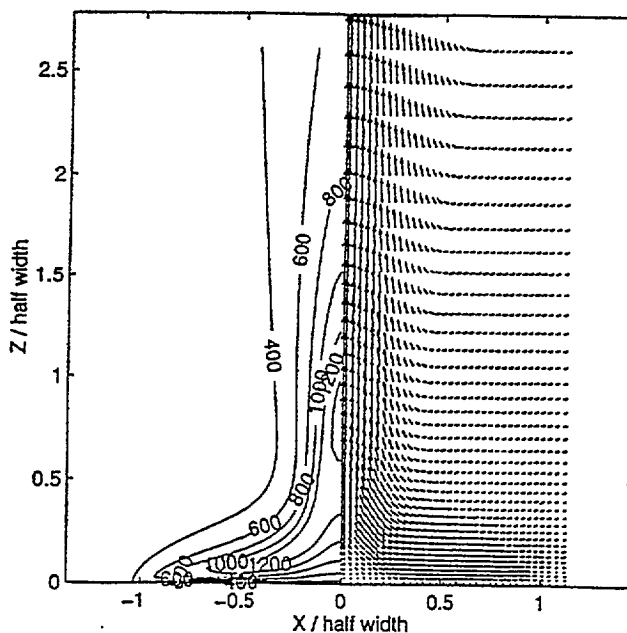


Figure 1: Temperature contours and velocity vectors

¹research supported through individual NSERC Operating Grants to E. Weckman and A. Strong

References

- [1] M. Ashrafzaadeh, A. B. Strong, and E. Weckman. In *Proceedings of The Combustion Institute, Canadian Section, Spring Technical Meeting*, 1996.
- [2] M. O. Annarumma, J. M. Most, and P. Joulain. *Combustion and Flame*, 85:403–415, 1991.
- [3] K. C. Adiga, D. E. Ramaker, P. A. Tatem, and F. W. Williams. *Fire Safety Journal*, 16:443–458, 1990.
- [4] E. J. Weckman and A. B. Strong. *Combustion and Flame*, 105(3):245–266, May 1996.

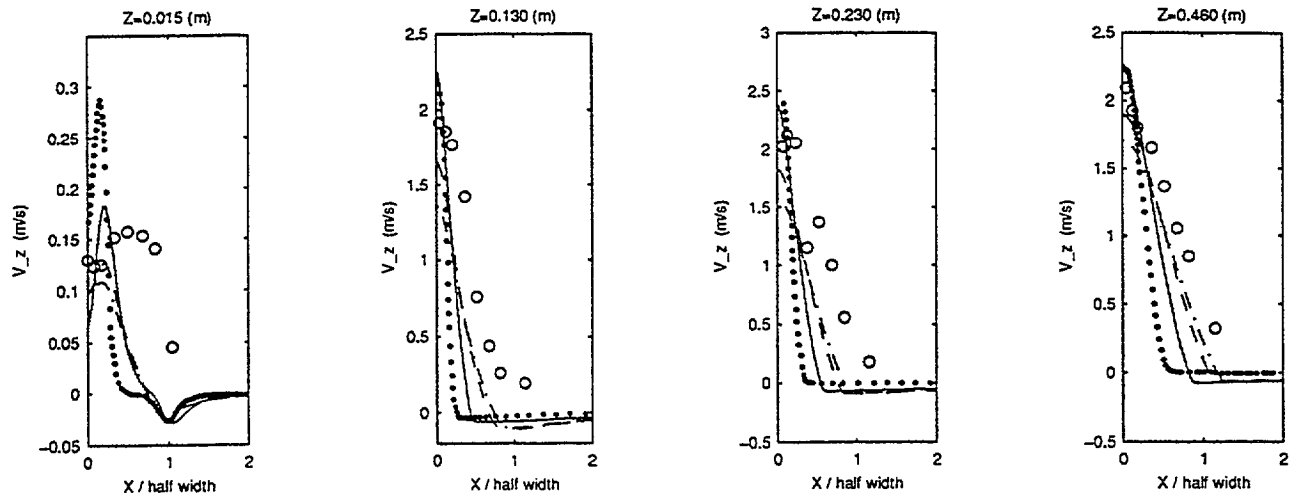


Figure 2: Cross-wise velocity distributions at different heights, see the caption of Fig. (3) for the legend.

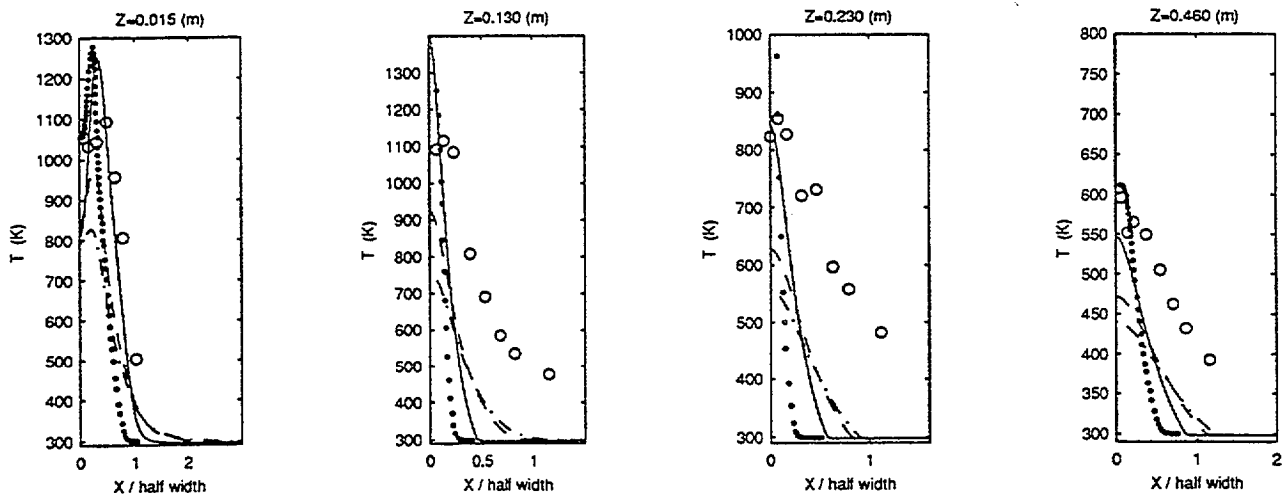


Figure 3: Cross-wise temperature distributions at different heights, \circ data [2], — case I with 20% radiation, \cdots Annarumma's model [2], — — case II with 10% radiation, —. case II with 20% radiation